Improving the Vacuum Surface Flashover Performance of Insulators for Microsecond Pulses

Jay Javedani
(925) 422-8569
javedani1@llnl.gov

One of the main areas of pulsed-power R&D is high-voltage insulation and dielectric breakdown, which is very often the limiting factor in attaining the highest possible performance in pulsed-power devices. The surface of an insulator exposed to vacuum can fail electrically at an applied field more than an order of magnitude below the bulk dielectric strength of the insulator. This mode of breakdown, called surface flashover, imposes serious limitations on the power flow into a vacuum region. While many researchers have studied this problem over several decades, there is still no consensus of opinion about the underlying mechanisms that fully explain this phenomenon.

A detailed understanding of the breakdown mechanism must be achieved so that improvements in the insulator performance can be made. This understanding is achieved by staging key computational models and supporting experimental configurations to induce flashover by introducing plasma or geometry effects to the insulator.

Project Goals

The objective of this investigation has been to address outstanding issues and establish a sound understanding of the mechanisms that lead to surface flashover, and evaluate the most promising techniques to improve vacuum insulators that enable high-voltage operation at stress levels near the intrinsic bulk-breakdown limits of the material. The high-voltage vacuum insulators for DARHT-II at LANL, for ZR at SNL, and for Phoenix at LLNL would directly benefit from this work. These results will also be very useful to other electrically stressful systems in the pulse power community.

Relevance to LLNL Mission

For many systems the delivery of pulsed power into a vacuum region is the most critical factor impacting performance and reliability, and the past two decades have seen a sustained growth in the diversity and complexity of device applications where vacuum is required to support high voltages and high electric fields. The applicability of our investigation in flashover performance spans scientific apparatus such as high-current particle-beam accelerators, high-power radio frequency and microwave sources, high-power laser sources, pulsed neutron sources, nuclear weapons effects simulators, lightning and electromagnetic pulse effects simulators, x-ray and proton radiography machines, inertial fusion drivers, directed energy weapons, and electromagnetic launchers. As such, the results have a significant impact on the LLNL national security mission.

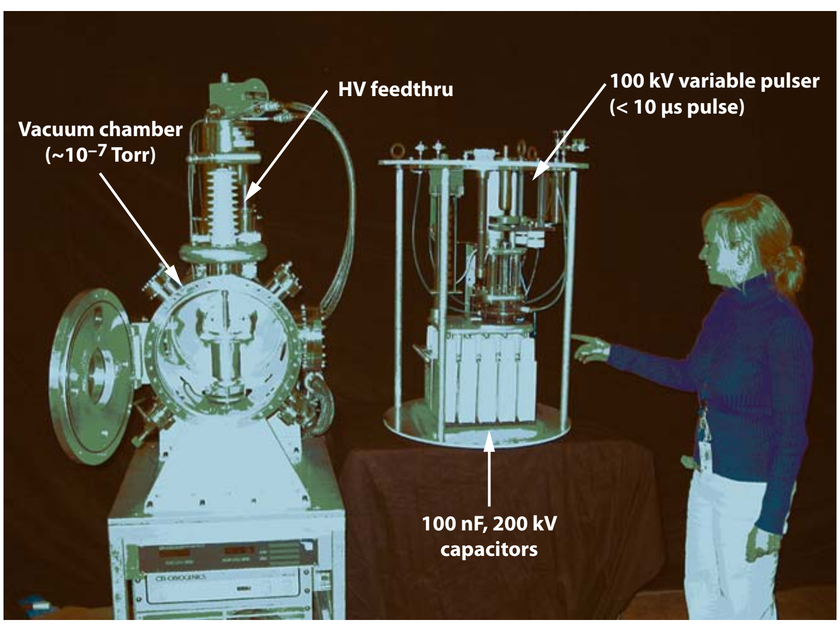

Figure 1. Operational testbed.

FY2006 Accomplishments and Results

Computational and circuit modeling was used to design an experimental testbed (Figs. 1 and 2) to study the insulator breakdown mechanism. The testbed was fabricated and assembled and is operational at LLNL.

The testbed is comprised of a vacuum chamber (70 l, 10^{-7} Torr) with several access ports; a variable 100-kV pulser with 200-ns rise-time and up to 10-µs flat-top pulses that is connected to the anode electrode disk by a HV cable through a vacuum feedthru; a spring-loaded cathode electrode disk that is set at 1.0-cm gap distance from the anode; a liquid voltage resistive divider (VRD) monitoring the output of the pulser; and a Pearson 110 current transformer measuring current on the cathode support stalk.

To investigate surface flashover in the widely used 45˚ conical insulator configuration, we installed a 45˚ conventional HD polyethylene insulator in the gap (visible in Fig. 2). With applied +100-kV pulses of 5 µs duration, the insulator held off the applied voltage, but experienced flashover if a source of plasma/electrons in the form of a small piece of velvet (1.0-mm diameter) was introduced in the vicinity of the insulator on either of the electrode's surfaces. Figure 3 shows the voltage collapse and drawn current for the cases when the velvet is placed on the surface of the cathode insulator at discrete distances away from the cathode triple junction (CTJ) for an applied voltage of +80 kV. Plasma expansion velocities of 1.4 to 2.7 cm/µs are inferred from these signals. The actual flashover occurs when the plasma that is launched from the cathode reaches either the insulator or the anode electrode, whichever happens first. The insulator, however, provides a much quicker conduit to the anode electrode at ns time scales that cannot be resolved by present 20-MHz bandwidth-limited voltage and current probes.

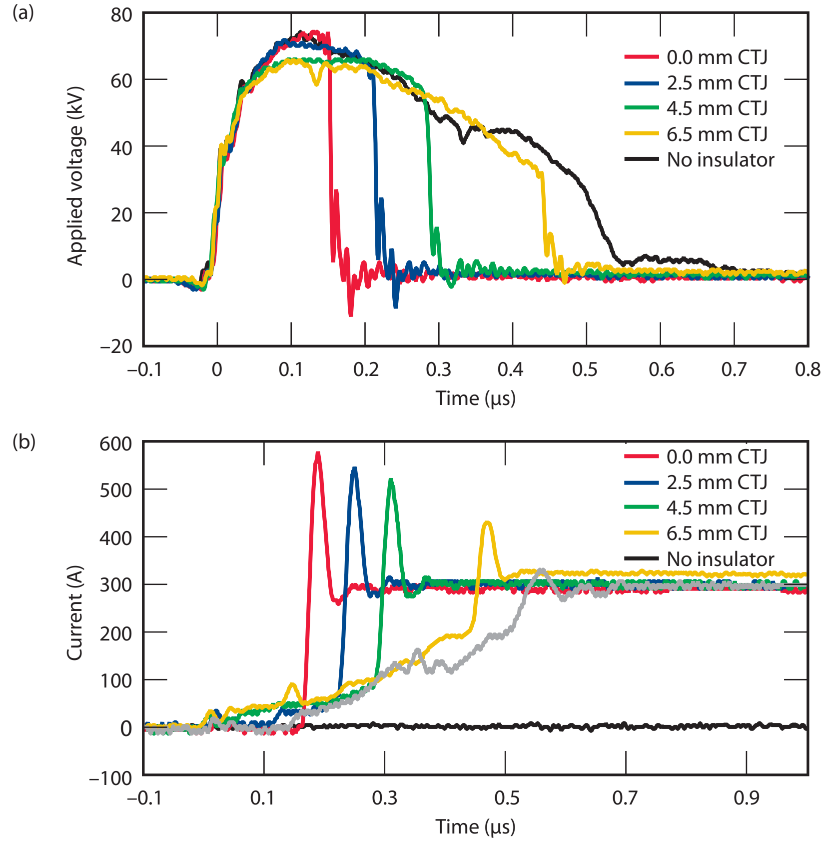

Figure 3. (a) Voltage waveform, and (b) current waveform, for +80 kV-discharge for velvet at different positions of CTJ.

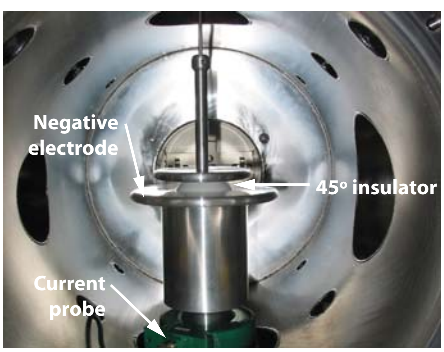

Figure 2. Test chamber with a HD polyethylene insulator installed between electrodes.

Related References

1. Anderson, R. A., "Surface Flashover: Three Decades of Controversy," *Fourteenth International Symposium on Discharges and Electrical Insulation in Vacuum*, Santa Fe, New Mexico, September 1990.
2. Stygar, W. A., *et al*., "Improved Design of a High-Voltage Vacuum Interface," *Phys. Rev. ST Accel. Beams*, **8050401**, 2005.
3. Houck, T. H., *et al*., "Study of Vacuum Insulator Flashover for Pulse Lengths of Multi-Microseconds," *LINAC*, Knoxville, Tennessee, August 2006.

FY2007 Proposed Work

The detailed electron dynamics prior to and including flashover are not yet fully understood and an investigation has been limited by the temporal and spatial resolution of our experimental and analytical tools. To overcome these limitations and enable the investigation, we will:

1. emplace faster diagnostic probes (D-dots with 3-GHz bandwidth) to resolve the details of the insulator flashover;
2. replace the solid-anode electrode with a thin aluminum foil backed with BC422 scintillator to facilitate pictures of the expanding plasma from its initiation point with a fast intensified camera; and
3. introduce a secondary electron avalanche physics capability into a 2-D/3-D programmable intelligent computer (PIC) code and verify its accuracy for our application.

During FY2007 we will complete these tasks and execute a detailed investigation of the phenomenology prior to completing a physics description and extracting the engineering guidelines that are critical to our support of programs.